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The environmental paradox in generation: How South America is gradually becoming more dependent on thermal generation

Santiago Arango [a,b,1,2], Erik R. Larsen [a,*]

[a] University of Lugano, Switzerland, Via Buffi 13, CH-6904 Lugano, Switzerland
[b] Complexity Center, CeiBa, Universidad Nacional de Colombia Medellín, Colombia, Carrera 80 # 65 – 223 Bloque. M8a-211, Medellín, Colombia

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ABSTRACT

There has been an increasing focus on global warming, emission of green house gases (GHG), and the problems this might create. In this article, we review the trend in sustainable and renewable electricity generation in South America, where the generation portfolio increasingly depends on thermal generation, in particular gas. South America is a region that has relatively low emissions, but the current development is not desirable in environmental terms. We analyze the underlying reasons for this development, which is related to security of supply, deregulation, and the cost of renewable energy. We review and discuss the policies to promote renewables in the region. We analyze the potential advantages and drawbacks of different types of market interventions, such as direct subsidies that create potentially strong market distortions, more sophisticated market interventions that might be less intrusive but not necessarily as effective as, e.g. firm energy markets. We also review market-based solutions such as the Clean Market Mechanism and its potential, and the use of renewable electricity in non-interconnected zones, which might be one of the most economically attractive applications of renewables. However, without a stronger and more aggressive intervention from the governments in the region it is unlikely that the increase in thermal generation can be stopped.

Contents

1. Introduction

During the last decade there has been an increasing focus on global warming, the emission of CO_2 and other greenhouse gases (GHG), and in general the impact that human activities have on the climate and the problems this might create. There has been a series of international agreements such as Kyoto, and more recently the Johannesburg, Rio, and Copenhagen meetings, where the international community, with more or less success, has agreed to reduce emissions. Thus, there is a general consensus about the need to reduce emissions, but there is less agreement on how it should be done, who should do it, and what it will cost [1,2].

One of the major contributors of GHG emission is the generation of electricity, or more specifically the use of thermal generation capacity, based on oil, coal, and gas. Generation capacity based on coal is normally considered the worst polluter, followed by oil and then gas; however, even gas contributes significantly to emissions [3]. Other generation technologies not contributing to emissions include nuclear, as well as alternative

* Corresponding author. Tel.: +41 58 666 4639; fax: +41 58 666 4647.
E-mail addresses: saarango@unal.edu.co (S. Arango), erik.larsen@usi.ch (E.R. Larsen).
[1] Tel.: +41 58 666 4474; fax: +41 58 666 4647.
[2] Tel.: +57 4 4255371; fax: +57 4 2341002.

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energy sources such as wind, solar, and hydro plants (both large and small-scale plants). There are well-known environmental problems relating to nuclear plants (such as radioactive waste) and large-scale hydro plants (local environmental problems with dams), which we do not deal with in this paper. For a country trying to reduce emissions the use of renewable resources for generation should ideally be the first choice both for capacity expansion and when replacing existing generation.

In Europe and the US there has been an increasing focus on the use of renewable technology, in particular wind, which has reached a significant level of contribution to the generation of electricity in some countries [4]. Other technologies, such as photovoltaic, are expected to contribute more over the next decade [5]. However, there is one current problem with most of the renewable technologies: they are still relatively expensive compared to conventional thermal solutions, thus, "*The growing interest in the establishment of a minimum share of renewable sources in the world energy matrix, after the Johannesburg World Summit for Sustainable Development (WSSD), has raised the question about the means for such new technologies to compete with the traditional ones*" [6]. Renewable technologies have other advantages, not least the lower dependence on imports of oil and gas, and the financial uncertainty that is tied to oil in particular; however, this might not be enough of a benefit to compensate for the increasing cost to many developing countries.

We are focusing on South America, an area that has had a number of economic crises during recent decades, making the economic development rather uneven at times [7]. The region also has a high potential for development, and in periods like the present, we can observe rapid growth in most of the countries, if not in all. Economic progress, including the increase in GDP, requires continuous expansion of electricity generation, and energy sources become a strategic variable for sustain development [8]. Thus, in order to sustain the economic growth we ask the question: which technologies should be used for the expansion of the capacity, i.e. thermal, hydro, or renewable, while taking into account both environmental and economic considerations? The answer to this question will help us to understand the future emissions from electricity generation in South America, and is of interest as South America traditionally has been a relatively "clean" region, with the predominant "fuel" having been water.

In this paper we review the past development, and consider the future use, of renewable energy including hydro, in South America. As discussed above, the traditional renewable sources and technologies are relatively expensive even for developed countries; how can they then be used in developing countries such as those in South America? Furthermore, South America has for some time had, a relatively large hydro-based capacity. We are interested in the development and sustainability of this hydro-based generation over the past two decades, and the pressure from increasing demand for electricity in the future, as the economies expand. South America has had not only relatively low emission from electricity generation, but also has some of the world's largest absorbers, in the Amazon rain forest, which is also under increasing pressure from human development.

The paper is organized in the following way. We begin with an overview of electricity generation in South America, after which we consider in more detail four of the largest South American countries: Argentina, Brazil, Chile, and Colombia. We then highlight some of the incentives as well as problems for electricity generation using renewable resources, followed by a detailed discussion and conclusion.

2. The electricity sector in South America

South America has been the most progressive area in the developing world promoting deregulation in the electricity sector [9]. The countries of the region are similar on many dimensions, such as culture, language and generation technology, which provide an opportunity for comparing and contrasting choices made in the individual countries. The region has been, and still is dominated by hydro-generated electricity [9,10], which has led to relatively low CO_2 emission compared with the rest of the world.

Table 1 shows an overview of South America in terms of macro-economic indicators, energy consumption, and emissions by country. There is a wide variation in the region, from a GDP per Capita of US$ 1089 for Bolivia to US$ 8692 for Argentina, with an average of approximately US$ 4000/Capita. It also shows the relationship between economic growth and energy consumption, an important relationship for understanding the effect of future economic growth on the demand for electricity. The correlation is 0.83 between *GDP/population* and *electricity consumption/population*, emphasizing the close relationship between electricity consumption and development. Finally, the electricity consumption in South America is only 4.1% of the total world electricity consumption while the population is 5.8% of world population [11].

During the decades of the seventies and eighties, the electricity sector expanded via major infrastructure projects to promote economic growth and social development [12], while in the nineties the focus moved to improve efficiency through market mechanisms. Most of the countries in South America moved from monopolies to some degree of open and competitive markets,

Table 1
Main macro-economic indicators, energy consumption and emissions of South America.

Country	Population (Million)	GDP (Billion $)	GDP/population ($/Capita)	TPES (Mtoe)	Electricity consumption (TWh)[a]	CO_2 emissions[b]	Elect. Cons/population (kWh/Capita)
Argentina	39.13	340.15	8692	69.10	102.53	148.73	2620
Bolivia	9.35	10.19	1089	5.85	4.53	12.75	485
Brazil	189.32	765.13	4041	224.13	389.95	332.42	2060
Chile	16.43	96.17	5853	29.78	52.70	59.84	3207
Colombia	45.56	105.55	2316	30.21	42.05	59.39	923
Ecuador	13.20	21.42	1622	11.24	10.02	25.02	759
Paraguay	6.02	8.34	1385	3.97	5.42	3.56	900
Peru	27.59	70.60	2558	13.55	24.81	27.93	899
Uruguay	3.31	23.16	6997	3.19	6.77	6.14	2042
Venezuela	27.02	146.64	5427	62.22	85.79	149.20	3175
S. America	*376*	*1587*	*3998*	*453*	*724*	*824*	*1707*
World	*6536*	*37,759*	*5777*	*11,740*	*17,377*	*28,003*	*2659*

Source: [11].
[a] Gross production + imports – exports – transmission/distribution losses
[b] CO_2 emissions from fuel combustion only. Emissions are calculated using the IEA's energy balances and the Revised 1996 IPCC Guidelines.

Table 2
Installed capacity and hydropower potential in South America.

	Hydro (MW)	Thermal (MW)	Other (MW)	Nuclear (MW)	Total (MW)	Hydropower potential (MW)	Year
Argentina	9852	17,288	27	1018	28,185	44,500	2002
Bolivia	485	918	0	0	1403	1379	2006
Brazil	72,013	20,935	237	2007	95,192	260,000	2006
Chile	4900	8636	2	0	13,538	25,156	2006
Colombia	8950	4330	20	0	13,319	93,085	2003
Ecuador	1801	2196	0	0	3998	23,745	2006
Paraguay	8110	6	0	0	8116	12,516	2003
Peru	3214	3443	1	0	6658	61,832	1996
Uruguay	1538	690	0	0	2228	1815	2006
Venezuela	14,597	7618	0	0	22,215	46,000	2002
Total	125,461	66,061	287	3025	194,851	570,028	

Source: [27].

looking for more efficiency, reliability, and higher quality, all at a lower price [13,14,15]. Chile was the first country in the world to move in this direction, as it started the deregulation and privatization process in the eighties [16]. Argentina used an adapted version of the Chilean model in the early nineties [9] followed by countries like Ecuador and Peru using fundamentally the same model. Colombia, on the other hand, adapted the British model in the mid-nineties [17], while Brazil developed its own model combining different elements from the various experiences in the region. The electricity sector in South America is predominantly hydro-based, making it different from other large regions and creating its own issues in the running and regulation of the deregulated markets. These deregulated markets have managed to make adjustments in the regulation and market rules to overcome some of the general difficulties in market-based systems as well as some of the idiosyncratic regional problems, with the aim of improving the systems' efficiency, and reducing their vulnerability [9,10,18,16].

In this study, we use a definition of renewable power generation to include the six main renewable energy technologies, which are: small hydropower, solar photovoltaic, concentrated solar power, bio power, geothermal power, and wind power [19]. We also include large-scale hydro-electricity because of its importance in the region, even though it is frequently viewed as a non-environmentally friendly technology due to its impacts on communities and the local environment [20,21,22]. While in the nineties no energy policies for renewable energy were considered [23], renewable energy in South America has nevertheless played an important role in the electricity sector, due in particular to the large proportion of hydro-electricity. Hydro-electricity accounts for 64% of the total installed capacity in the region as is shown in Table 2; and moreover, the potential for hydro-electricity is around three times the total current installed capacity. The region is endowed with abundant renewable sources for energy, the exact amount depending on the geology and geographical location of the specific country. Apart from the hydro potential, it receives abundant solar radiation with very little variation across the seasons, which potentially enables extensive use of photovoltaic generation [24]. Wind generation is taking hold in some areas such as La Guajira in Colombia and others [12,25] and some areas in Argentina such as such as Lerma Valley, Salta [26].

3. Evolution of renewable and hydro energy generation in selected countries

What systemic changes have taken place over recent decades in the mix of generation capacity in the four largest countries in South America? How has South America reacted during the last decade to discussion of lowering emissions, the Kyoto Agreement, and other initiatives? Can we track any changes in the use of renewable technology?

The main issue is that the technology mix has changed significantly over the last decade, and particularly in the period after deregulation. In Fig. 1 we are observing the share of hydro and thermal in Argentina, Brazil, Chile and Colombia. At the beginning of the nineties there was a very high proportion of hydro in Chile, Brazil and Colombia, up to more than 90% in some cases, while Argentina had around 40%, which is a situation that overall is favorable from an emission point of view. However, there has been a rapid penetration of fossil generation, particularly since deregulation. If we look at Chile, the fraction of hydro was over 80% in 1993, followed by a relatively sharp decline in the last half of the nineties, ending at around 53% today, which represents a fall of 27% points. In Colombia the fraction of hydro fell from 78% in 1994 to 66% in 1999, i.e. a fall of 12% points, and has stayed around this level since. The changes have been slightly less dramatic, but not less significant, in Argentina where the decline has been from around 45% to 37%, a 7-point decrease over a 4-year period in the last half of the nineties. Finally, Brazil has faced a similar declining tendency with a fall of 10% points in less than a decade. Similar reductions can be observed in other South American countries, e.g. Peru with a reduction from 54% to 46% between 1996 and 2007 [28], as well as Ecuador, showing a similar change.

The increase in fossil generation capacity is almost exclusively in combined-cycle gas turbine (CCGT), a development that makes South America similar to many countries in Europe and states in the USA, which have also significantly increased the use of CCGT. In the UK, all new technology in the last decade has been based on gas – sometimes described as the "dash for gas" [34]. However, there is a significant difference in terms of the environmental consequences of this change between South America and Europe. While in Europe the gas-fired capacity has, to a large extent, replaced coal-fired generation, in South America it has added to or replaced the existing hydro generation. Although it is not ideal for Europe, it has at least replaced old or potentially new coal-fired capacity and thereby reduced emission. In South America, however, it has covered the demand growth and has replaced old or potential new hydro capacity, thereby increasing their emission. This is the paradox: while we continue to discuss how to reduce emission and make the world more sustainable, we actually observe in South America the exact opposite: a movement away from what was one of the most sustainable electricity systems toward a system increasingly dependent on fossil generation.

As pointed out above, the increasing share in thermal generation is not exclusively a South American issue. A similar situation can be seen in well-developed electricity markets such as the UK; there the total capacity has undergone a net increase of 3.4 GW between 2004 and 2008 (3 GW and 1.5 GW from thermal

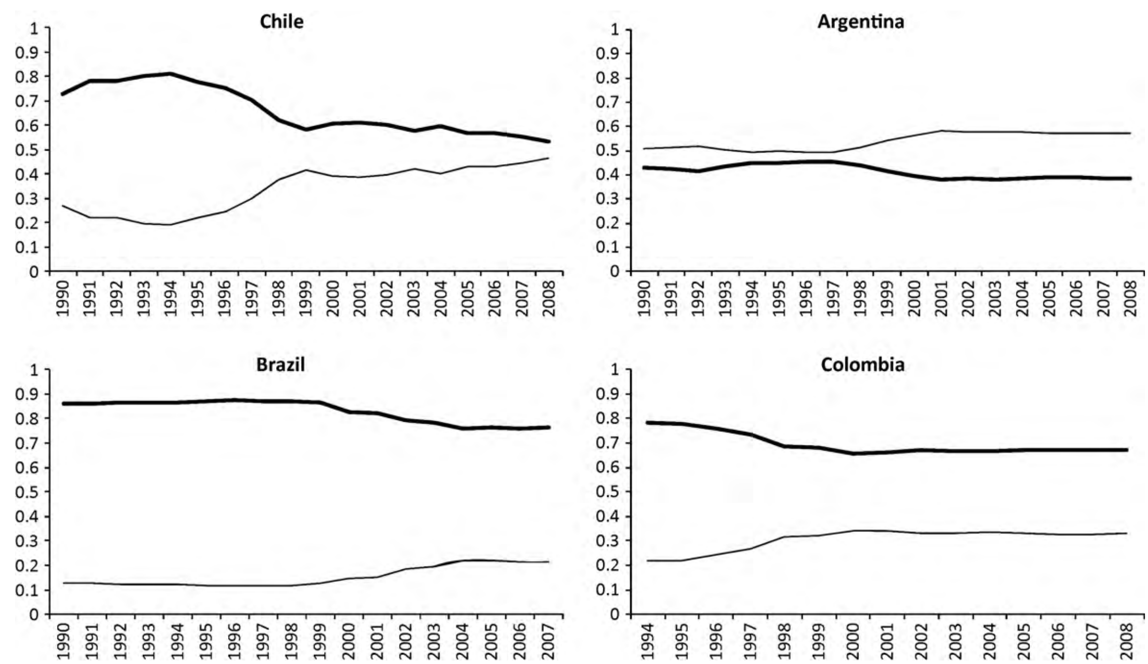

Fig. 1. Market share for hydro (bold line) and thermal (thin line) capacity in selected countries of South America. Source: for Chile: [29,30]; for Argentina: [31]; for Brazil: [32]; and for Colombia: [33].

and renewable energy respectively); however, the replacement accounts for 0.9 GW nuclear (non emission) and 0.2 GW of thermal generation, thereby increasing the share of fossil generation in the overall generation portfolio [35]. What is the cause for this increase in fossil fuel in the generation portfolio? We can see at least two reasons to explain why this is happening in South America, one is technical and relates to security of supply and the uncertainty of being dependent on hydro. The other is deregulation and the way in which electricity companies evaluate their investments. We will deal with them next.

The reliability or security of supply, of an electricity system, is a major concern for the electricity industry, its customers, and the political class. An important component is the choice of generation technology and the mix of generation technologies in the generation portfolio. In systems dominated by thermal generation, the critical factors are the capacity to supply enough electricity at peak hours, and the security of gas. In a hydro-dominated system, the critical factor is the ability of the industry to supply sufficient energy in (prolonged) dry periods [36] as the generation by hydroelectricity is a function of water resources being susceptible to weather conditions (while gas is often a political and economic issue not depending on weather conditions). One of the most significant weather anomalies in South America is caused by the macroclimatic phenomenon known as the El Niño-Southern Oscillation (ENSO), as described in more detail in Diaz and Markgraf [37]. ENSO is a quasi-periodic oscillation of the tropical Pacific Ocean that leads to changes in the rain regimes on the east coast of South America. The extreme phases of the ENSO are El Niño and La Niña. El Niño produces more extreme and longer dry seasons than usual in Colombia; for instance, the 1997–1998 event reduced the water inflow to reservoirs from an historical average of 2962 GWh/month to 2127 GWh/month in 1997, a reduction by almost 30% [17]. La Niña, on the other hand, intensifies the rainfall in Colombia, while at the same time causing extreme droughts in Chile. During the La Niña occurrence of 1998 and 1999, the Chilean electricity system faced not only random shortages but also, at the peak of the crisis, 3-h-long revolving blackouts [9]. For more details about different aspects of the ENSO phenomena in western South America, refer, e.g. to Waylen and Poveda [38]. Moreover, the vulnerability of hydro-dominated systems is also affected by climate change, e.g. in Brazil [39].

From the discussions above, the implication of relying on a large share of hydro is the difficulty of generating enough electricity in dry periods. In which case, introducing more fossil-based generation diminishes the reliance on uncertain weather conditions. However, the introduction of thermal generation has other difficulties, not only increase in emissions. Thus, in periods with abundant water resources (which could last for years), it might not be economic to run thermal plants for any significant period of time (unless given incentives by the regulator) as hydro can always underbid thermal capacity. Another drawback for thermal generation is that it requires fossil fuels. At times, Argentina experiences shortage in natural gas to supply its internal demand, including electricity generation [40], while Chile depends on Argentina's (unreliable) exports and new LNG plants that should come on line in a couple of years. In addition, the natural gas in the Southern cone faces a number of difficulties including political issues between Bolivia, Brazil, and Argentina [41], which affects the reliability of the electricity supply as the politics affects the flow of gas. Moreover, the occurrence of El Niño at the end of 2009 has led to increasing use of gas for electricity generation, consequently gas shortages have been observed in other sectors in the region [42].

The second reason for the increase in thermal generation is a mix of technology factors and deregulation. Before the deregulation of electricity systems, investment decisions regarding new generation capacity were made centrally by publicly owned companies or a ministerial planning body. This allowed for a long-term view of the investments, with relatively low uncertainties [43]. After deregulation, electricity companies have to deal with more risks, payback time, and rate of return on the investment, etc. This makes it difficult for most companies to consider large-scale hydro projects, which previously had been one of the trademarks of generation in South America. The uncertainty of electricity prices a decade ahead, possible delays, regulatory changes, and general cash flows make it difficult for companies to commit to large-scale projects that might take 10 years or more to complete. At the same time as deregulation began, CCGT technology became available. CCGT has significant cost

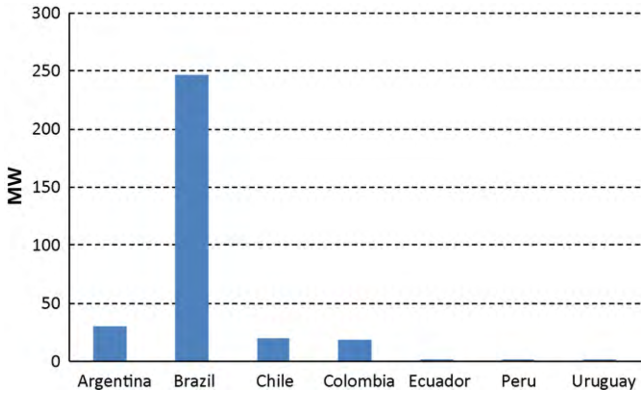

Fig. 2. Installed wind-energy capacity in South America [46].

advantages; even relatively small plants are competitive, making the investment less risky. The construction time is significantly shorter, in some cases less than 3 years compared with up to 10 years for large hydro projects. In other words, CCGT plants look much more attractive as a generation investment for most (private) generation companies. The same reasoning was behind the "dash for gas" in the UK [44,34] where the vast majority of new generation investment was gas fired.

What are the options for South America to turn this trend around and move back towards an increasingly sustainable development? Deregulation is unlikely to be reversed in the major countries and there is still a long way to go for renewables to become truly competitive. So far in South America renewable energy, apart from hydro, has not played any significant role in the generation of electricity; could it be changed? Before we move to look in more detail at these questions, we should note that the existing potential new hydro capacity currently accounts for around three times the current installed capacity (see Table 2) and there is a large potential for other renewable generation. Despite the potential of renewables the current penetration is very low. If traditional hydro technology is excluded, there are only promotional or marginal projects, which accounted for less than 1% of the total generation capacity in the whole of South America in 2006 [45]. Fig. 2 shows the current installed wind capacity in selected South American countries. As we can observe, Brazil has the largest installed capacity, which is more than six times higher than that of the next largest user, Argentina. However, even in the case of Brazil this is very little. Why is there so little wind energy in South America? In the following section, we try to understand this and what can possibly be done to change the trend.

4. Incentives and initiatives to promote renewable capacity

The electricity sector in South America has largely been market oriented for at least the last decade [9,47]. By adjusting the regulation, together with some direct interventions, the regulators have managed to keep the electricity sector in a state where it could, in most cases, cover the demand. However, explicit policies for investing in renewable energy are missing and, due to the changing market structure, even the traditional hydro generation (traditional for the region) has become less attractive for investors [12]. Policies have been oriented towards attracting investments in any kind of capacity (technology) under competition, and such policies have effectively led to a more thermal-oriented portfolio. Nevertheless, new initiatives are being proposed and implemented; in this section we will describe some of the most important and relevant initiatives.

By now, more than 60 countries have implemented some type of policy for renewables in electricity generation [4]. In South America, incentives and different financial schemes to promote the use of renewable energy depend on the individual country, with significant variation. The policies have some similarities, but there are no coordinated initiatives in the region. Table 3 presents the most relevant initiatives and policies that are currently in force to promote the use of renewable sources for generation capacity.

The table shows that a number of different policies are currently implemented, such as tax reduction, feed-in tariffs, subsidies, etc. Most policies are focused on multiple renewable energy sources. Notice that all of the countries have some policies to promote investments in renewable energy. Furthermore, most of the policies have been implemented during the current decade, which makes it more difficult to judge their effectiveness. Although policies have not been in place for long, there is a prevailing feeling that most of them have not been very effective at promoting large-scale investment in renewable generation, which is consistent with the evidence of the previous section.

Renewable energy can be produced both on-grid and off-grid. South America is a region with vast rural areas without electricity, where renewable energy sources might be the most efficient way of delivering electricity. In isolated rural areas, small-scale renewable energy projects can simultaneously increase energy access, improve the quality of life, and the energy-development path [49,50]. Decision support tools has been developed and used to help decision makers to select the best technology, with multi-criteria models focused on sustainability, e.g. in Cuba [51]. Off-grid projects are often associated with poverty reduction programs, and a number of policies have been developed to promote the use of renewable energy in this context. This includes programs such as the PAEPRA Argentine Rural Electrification Program; PRONER National Rural Electrification Program (Bolivia); Rural Electrification Programs with renewables in Brazil [50]; and the Rural Electrification Program (Chile), among others [52].

So far, there is no general agreement about the effectiveness of the incentives. Evaluation of the different initiatives has showed mixed results, while the evidence that we present and discuss clearly shows a region that is becoming more and more thermal dependent. The new laws implemented in Argentina (see Table 3) have been analyzed by Guzowski and Recalde [53], who claim that results of the legislation are not good enough and should be further refined by the Government. In Colombia, simulation studies have indicated that it is more efficient to promote renewable generation with direct subsidies rather than fiscal policies [12,25], which is contrary to the current legislation. PROINFA (Program of Incentives for Alternative Electricity Sources) in Brazil was designed to three specific technologies (wind, biomass, and small-scale hydro); however, the formulation seems to promote more biomass-fired generation, contradicting the initial aim, which was to diversify the energy matrix [54].

Above, we reviewed some of the significant current initiatives for investing in renewables, but there are complementary policies developed at the international level to promote renewable generation in developing countries. An example of this is the Kyoto Protocol, which established a mechanism to promote "clean" development projects in some developing countries. Renewable energy projects can apply to participate, under certain conditions. In the next section, we present and review this mechanism.

5. Alternative instruments: clean development mechanism

The Kyoto Protocol (KP) created in 1997 the obligation for industrialized countries that ratified it to reduce the emissions of GHG, with specific targets, by 2012. The protocol was thought to be an agreement to improve the climate system, where the core principle [55] was "the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capa-

Table 3
Promotion policies in force for renewable sources of energy for electricity production.

Country	Policy name	Type	Target	Year
Argentina	Promotion of renewable sources of energy for electricity production	Incentives/subsidies Policy processes	Multiple renewable energy sources	2006
	National strategic plan for wind energy	Incentives/subsidies Policy Processes Public Investment	Wind	2005
	Renewable Energy & Energy Efficiency Partnership (REEEP)	Education and outreach Policy processes Voluntary agreement	Multiple renewable energy sources	2002
	Law no. 25,019 on the promotion of wind and solar energy	Financial Incentives/subsidies	Solar Wind	1999
	Proyecto de Energia Renovable en el Mercado Electrico Rural (PERMER)	Incentives/subsidies	Multiple renewable energy sources	1999
Brazil	Brazil national climate change plan	Policy processes	Bioenergy Hydropower Solar photovoltaic Solar thermal Wind	2008
	Luz para Todos (Light for All) electrification program	Incentives/subsidies Policy processes Public investment	Multiple renewable energy sources	2003
	Program of incentives for alternative electricity sources – Programa de Incentivo a Fontes Alternativas de Energia Elétrica	Incentives/subsidies Regulatory instruments Tradable permits	Bioenergy Hydropower Wind	2002
	Renewable Energy & Energy Efficiency Partnership (REEEP)	Education – Outreach Incentives/subsidies Policy processes Voluntary agreement	Multiple renewable energy sources	2002
Chile	Non-conventional renewable energy law http://www.iea.org/textbase/pm/%3Fmode=re%26id=4351%26action=detail	Regulatory instruments	Bioenergy Geothermal Ocean Solar Wind	2008
	Rural Electrification with Renewable Energy Programme	Education/Outreach Financial Public investment	Hydropower Solar photovoltaic Wind	2001
Colombia	Law 788 of 2002	Tax reduction	Multiple renewable energy sources	2002
Peru	Promotion law for electricity generation with renewable energy	Feed-in tariffs	Multiple renewable energy sources	2008
	Accelerated law for investment in renewable energy	Financial	Multiple renewable energy sources	2008

Source: Argentina, Brazil, Chile, [48]; Colombia, [12]; Peru, [28].

bilities" [56]. The protocol established GHG emission reduction targets of 5.2% below 1990 levels by 2008–2012, and it came into force on July 16th, 2005. A number of non-Annex I Parties could participate in the Kyoto Protocol by developing projects with the clean development mechanism (CDM). The protocol establishes three different mechanisms to reduce emissions: international emissions trade, joint implementation, and a clean development mechanism (CDM).

The CDM is a project-oriented mechanism to finance any projects in developing countries that can obtain "certified emission reductions" (CERs); the CERs are revised and issued by the United Nations Framework Convention on Climate Change—the UNFCCC—and are measured in tons of CO_2 [55]. Renewable energy projects can get CERs and sell them in the international carbon market; thereby increasing the cash flow of the project. According to the Kyoto Protocol, "the purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention. . .." [56], emphasizing the focus on sustainable growth in developing countries.

In developing countries, such as in South America, the CDM is an opportunity to finance renewable energy projects. Given that South American countries have no international obligation to reduce emissions, as agreed in the Kyoto Protocol, any emission reduction achieved by a particular (renewable) project can be sold in the carbon market, thereby providing an alternative stream of income from the project and increasing its financial viability. However, not all projects, even if based on renewable energy, are eligible for the CDM. Paragraph 5, Article 12 of the Kyoto Protocol [56], states that the emission reduction should be certified on the basis of:

(a) Voluntary participation approved by each Party involved;
(b) Real, measurable, and long-term benefits related to the mitigation of climate change;
(c) Reductions in emissions that are additional to any that would occur in the absence of the certified project activity.

The operation of the CDM began in 2006. Since then, more than 1000 projects have been registered and they are expected to reduce emissions by more than 2.7 billion tonnes of CO_2 equivalent for the

Table 4
Reduction in emissions by clean development mechanism CDM projects up to October 2007.

Country	Hydroelectric projects		Wind projects	
	No	Mton CO_2	No	Mton CO_2
Argentina			1	0.19
Bolivia	1	0.99		
Brazil	21	7.07	4	1.19
Chile	3	1.26		
Colombia	3	0.88	1	0.13
Ecuador	4	1.93		
Total	32	12.13	6	1.51

Source: [27].

initial period of the Kyoto Protocol, 2008–2012 [57]. South America has been active with this instrument. Today, South America accounts for 24% of the total registered projects, where Asia and the Pacific have 73% [57]. The use of the CDM has led to a total reduction in 2007 of 12.13 Mton CO_2 resulting from hydroelectric projects, and 1.51 resulting from wind generation projects, as is shown in Table 4.

The total number of projects up to 2008 under the CDM, in Latin America, is 439 [57]; however, Table 4 only lists the 38 projects related to electricity generation. The CDM has shown itself to be a successful market-based mechanism in some cases not only for reducing emissions in developing countries [55], but also for increasing technology transfer to developing countries [58]. However, most of the CDM projects have been directed to reduction of hydrofluorocarbons, of N_2O, and of landfill gas [55], which shows the limitation of the applicability of policy for the electricity sector in the region. It could have been expected that electricity generation would have been one of the largest users of this mechanism but the above shows that less than 10% of the uses have been in electricity generation.

Due to the limitation of the current formulation, the CDM may fail to deliver both the goals: decreased emission and sustainable development. There is an emerging consensus that the CDM mechanism should be refined to fulfill its dual goals better [55,59]. The future of this policy depends largely on new negotiation following the COP15 in Copenhagen; the CDM could become more effective in promoting renewable energy in developing countries in general, and in South America in particular.

In the previous sections we have described the current situation regarding renewable energy for electricity generation in South America. We have presented an account of the undesired reduction (in environmental terms) of hydro capacity (and therefore of renewable energy), as well as the status in terms of current installed capacity for renewable energy and promotion policies. We have also reviewed one of these global policies in detail and shown that it has not been very effective in the promotion of renewable policies in South America.

6. Discussion

Renewable energy has played an important role in South America in the past, and presents the opportunity and potential for playing an equally important role in the future. However, if the current trend continues, this potential might not be fulfilled. South America has a long-term increasing demand for electricity that is needed to sustain the economic and social development of the continent. We observed in the last decade an increase in the share of thermal generation in the overall generation portfolio as well as in new investments for the largest countries in South America. While a number of current programs are trying to reverse this trend, we see little evidence that they are successful; we suggest that more aggressive policies might be needed to fulfill the potential of renewable resources for electricity generation in the region.

As electricity markets do not have internalized environmental costs, only regulation plus promotional and support policies will guarantee the economic viability for renewable energy as in some European countries [60]. This, however, raises a number of issues about what needs to be in place for this to happen. The (government) promotional policies that have been used with success in some European countries and in parts of North America need to be carefully examined before they can be applied in developing countries such as in South America. What criteria should these policies fulfill?

Firstly, the policies should consider general factors such as the particularities of national regulatory environments, past history and specific energy resources, and their influence on the effectiveness of the policy. For instance, Kissel and Krauter [60] evaluate the development of wind power under different promotion policies such as renewable portfolio standards (obligation to include renewable energy in the generation portfolio), fuel generation disclosure rules, mandatory green power options, and public benefits funds. They found a positive effect on wind power from renewable portfolio standards, which shows the effectiveness of policy promoting wind; in contrast, a negative relationship was found between the establishment of wind energy and retail choice (the electricity source can be chosen by customers, e.g. green power). Another example: market-based solutions might be less likely to increase the share of electricity from renewable resources in the generation portfolio. Currently, the only large-scale hydro projects are pursued by publicly owned companies, which have less short-term financial pressure; the same is true for most renewable energy projects in South America.

The second thing to consider is the economic situation in the region, and how that might require further adjustment of policies used in developed countries, in order to become effective. For instance, Kissel and Krauter [60] studied policies for promoting wind in Brazil; they observed the importance of high revenues during the amortization period of the loan, due to the high interest rate of the loan used to finance the investment. The feed-in tariffs can be considerably reduced once the capital cost is amortized. In Colombia, Zuluaga and Dyner [12] suggest, based on a simulation study, that a more efficient policy such as direct subsidies is more effective than fiscal policies such as income tax exemptions.

Another issue is that in South America there are no general or agreed goals in terms of reduction of emission or share of generation based on renewable resources [61]. One reason for this could be that South America does not have a coordination mechanism such as the European Union has, which can set (agreed) goals for most of Europe. The European Union has, e.g. its 20/20/20 goal for the member states (a 20% reduction of the 1990 emission levels and 20% renewable energy sources, all by 2020). Such a coordination mechanism would certainly support and reverse the tendency towards more thermal generation.

There are a number of options for expanding electricity generation. Each technology has advantages and drawbacks depending on how the projects are evaluated, in terms of cost, time, return on investment, etc. Of the more conventional generation technologies such as pulverized steam coal, combined-cycle gas turbines (CCGT), and nuclear power [62], the first has a relatively short building time, while nuclear is among the longest of all technologies to build. Similarly, hydropower with significant reservoir storage takes as long as nuclear to build, while run-of-river hydro is faster but normally smaller and less reliable. These technologies are generally competitive, but the likelihood of nuclear and large-scale hydro being built in competitive markets by private firms is relatively small. This is because such technologies have long lags before they can generate revenues,

Table 5
Cost of traditional and renewable energy technologies; current and expected trends.

Energy source	Technology	Current delivered cost of energy (US$-¢/kWh)[a]	Expected future costs beyond 2020 as technology matures
Coal	Grid supply	4.4–7.4	Declining capital costs, function of (real) price of fossil fuels
Gas	Combined cycle	3–5.9	
Delivered grid electricity from fossil fuels	Off-peak	3–4.4	
	Peak	22–37	
	Average	12–15	
	Rural electrification	37–118	
Nuclear		5.9–9	4.4–7.4
Solar: thermal electricity	Annual insolation of 2500 kWh/m^2	18–27	5.9–15
Solar: grid connected photovoltaics	Annual 1000 kWh/m^2 (e.g. UK)	74–118	~12
	Annual 1500 kWh/m^2 (e.g. Southern Europe)	44–74	~7.4
	Annual 2500 kWh/m^2 (e.g. lower latitude countries)	59–89	~15
Geothermal	Electricity	3–15	1.5–12
	Heat	0.7–7.4	0.7–7.4
Wind	Onshore	4.4–7.4	3–4.4
	Offshore	8.9–15	3–7.4
Marine	Tidal barrage	18	18
	Tidal stream	12–22	12–22
	Wave	12–30	7.4–10
Biomass	Electricity	7.4–22	5.9–15
Biofuels	Ethanol (cf. petrol & diesel)	4.4–13(2.2–3.2)	3–5.9(2.2–3.3)
Hydro	Large scale (small scale)	3–12(5.9–15)	3–12(4.4–15)

Source: [63].
[a]Original data is in Euro-¢/kWh; we approximated with 1 US$ = 0.67629 Euro, based on the exchange rate at October 29th 2009 (www.oanda.com).

together with uncertainty about the demand for energy a decade ahead and thereby the price, as well as perceived environmental concerns (not related to emission) that are among many other potential issues. While there has been a rapid growth in CCGT in South America and Europe, coal is still used widely in other areas of the world as well as in some parts of South America. This is the "competition" that renewable sources are facing. For renewable energy sources (other than hydro), the costs are often seen as the main barriers [12,63]. We have observed significant cost reductions and efficiency gains over the last decade in the electricity sector, but in most cases renewable electricity generation is still not competitive with thermal generation, e.g. on-shore wind power is the only source that can be competitive under very specific local conditions [62]. The current and expected costs of both traditional and renewable energy technologies are listed in Table 5 [63].

The current pool prices in South America are around US$ 4 kWh. Comparing this with Table 5, most of the renewable energy generation technologies are not economically competitive. At first glance, the best option in terms of cost is large-scale hydroelectricity. However, it is extremely risky for a private company to invest in projects with such a long lead time, e.g. it can take up to 10 years before a large hydro project starts to produce electricity. It is very difficult to get external financing and furthermore the price of electricity would be unknown and could change significantly over that time horizon (see [64] for an example). While wind power is close to being competitive it should be considered that the lower cost applies in extremely favorable conditions, and the technology in general is not yet viable without some form of support or regulation. The remainder of the renewable technologies are much further away from being commercially competitive. Thus, we could argue that renewable energy might be suitable for rich countries but less so for developing countries from an economic point of view (e.g. Colombia [65]). Following from this, if the markets are left to their own decisions the decline in sustainable generation is likely to continue in South America.

As an example of the need for new electricity generation capacity we can look at Brazil, which requires around 4 GW in order to sustain an economic growth rate of 4%, and is planning substantially more thermal generation over the next 10 years, where the plan is to increase the installed gas capacity by around 40% [66]. The most ambitious plan for renewable energy in South America is the PROINFA program in Brazil. The aim of this program is to support the installation of wind power turbines for a total of 1100 MW [60], which is only a marginal 0.2% of the installed capacity and only around 25% of the planned new capacity. Ecuador has not been able to keep the expansion of electricity generation capacity in line with the growth in demand, reducing the reserve margin for future adverse climatic conditions [67], and Peru where 66% of the new capacity in the period from 2008 to 2012 will be based on natural gas generation [28].

Another example is Colombia, which has developed and implemented a new policy for incentives in power generation including an alternative incentive structure—the reliability charge—in order to secure the supply in periods with adverse weather conditions, mainly the ENSO. The market pays for firm energy[3] in a certain period and it is assigned through auctions [36,68]. The firm energy creates obligation for the generators and implies an expansion of the electricity sector. Following the first capacity actions, the electricity system should be expanded with 352 MW in thermal and 78 MW in hydro-electricity by 2013, implying that the trend towards an increasing amount of thermal capacity continues. However, by 2018 the electricity system is expected to bring on line almost 3000 MW of hydro-electricity [33], capacity initiated by generation companies that are still publicly owned. In this sense, Colombia will have reversed the trend as it is back to 72% of hydro and 28% thermal generation capacity. However, as we discussed earlier, this is only likely to happen in deregulated markets if the investments are made by

[3] Normally, firm energy is defined as "the amount of energy a generator can deliver per month during an exceptionally dry period (a worst-case benchmark). A typical thermal unit is certified at its nameplate capacity times its average availability, such as 92% of nameplate. In contrast, a hydro resource's firm energy may be well below its nameplate, say 35%, due to a limited water reservoir and low inflows during dry periods" [36].

public companies with different investment and return policies than privately owned firms.

7. Conclusion

In this paper, we have highlighted the trend away from sustainable and renewable electricity generation in South America, where the generation portfolio increasingly depends on thermal generation, in particular gas. There are a number of reasons for this, including economics, reliability of generation, and the "logic" of the market, reasons that are not likely to change in the short term, so the current trend will most likely continue. Furthermore, there are other national contributing factors which we have not discussed here as they are not shared in the region, e.g. low gas price for the last few years in Argentina. For it to change, there is a need for decisive interventions in the market to promote renewable generation; however, these interventions are likely to be expensive, in terms of subsidies or in increased electricity prices. Thus, the cost for renewable electricity may not be affordable for countries in South America as it might jeopardize future economic growth that is needed to promote development.

We discuss the potential for hydropower in South America. Large-scale hydro plants normally have the advantage of low costs, but long construction delays, high capital cost and a long capital recovery period. Private companies with a short or medium term horizon may not be willing to make this type of investment, even in relatively favorable economic periods and much less so during an economic crisis. Only government or publicly own companies can make this type of long-term, high-risk investment. Direct subsidies create potentially strong market distortions, while more sophisticated market interventions may seem to be less intrusive but not necessarily as effective. This is the case with firm energy markets in Colombia (also implemented in England and Wales), which are expected to encourage the building of more than 20% of the current installed capacity of large-scale hydro capacity. While the initial purpose of the firm energy markets was to provide market stability and security of supply, a new dimension to favor renewable energy could be included, although this might defy the original purpose of creating stability.

Instead of large-scale hydropower plants, direct subsidies and feed-in tariffs appear to be more appropriate to the promotion of the remaining renewable energy sources. The basic principle is to use government support to overcome the cost barrier. Moreover, governments in the region have objectives that go beyond the boundaries of the interconnected electricity systems, to the electrification of rural and non-interconnected zones. This might be an area where the economic disadvantage of renewable sources for electricity generation is smaller as there is no pre-established infrastructure and the cost of establishing thermal generation might be higher than average. The promotion of renewable energy sources in these areas would provide electricity and support in poverty reduction, as well as the penetration of, and learning about, clean technologies. Most likely there would be international organizations and funds willing to provide financial help for the development and penetration of these renewable technologies in disadvantaged areas. It could be supported by research programs and international collaboration focused not only on technological development but also on policy and planning analysis of electricity systems in rural areas.

The big question in the end is who is going to pay for South America staying green—something which will benefit everybody? We have discussed how the promotion of renewable generation will be more expensive than going with thermal generation. It is also clear that the four countries that we looked at in South America are unlikely to scale back deregulation of the electricity markets, but somebody would have to pay for increasing the share of renewables in the generation portfolio. If renewables are mandated by the government the cost to the private companies would have to be recovered through higher electricity prices, something which a large part of the affected societies cannot afford to pay, and which might affect the economic growth of the countries. On the other hand, if subsidies are offered as incentives by the governments then the money will have to come through taxes, again with a negative effect on development. The only short- to medium-term solution is to further develop and establish mechanisms such as the clean development mechanism and other international supports, both technological as well as economic.

Despite the fact that the region is still doing well in terms of emissions of GHG, there is a drawback to moving on the same historical track of fossil-based energy as Europe and the USA have followed. The current situation in South America is not critical by international standards, but we have shown that there is a significant change underway, a change that has gathered pace over the last decade. It should also be clear that the sooner this trend is reversed the easier it will be. Following the Copenhagen meeting we believe that the region should not remain apart from the discussion as this might be a unique opportunity for developing a plan for the whole region.

References

[1] AP. Developing nations get climate concessions. Associated Press; 2009, November 3rd.
[2] J. Benjamin, M. Keen. Climate policy and the recovery. IMF Staff Position Note SPN 09/28; 2009.
[3] IEA. CO_2 emissions from fuel combustion highlights. Paris, France: International Energy Agency OECD/IEA; 2009.
[4] REN21. Renewables 2009 Global status report, Paris: REN21 Secretariat and Washington, DC: Worldwatch Institute; 2009.
[5] Bagnall DM, Boreland M. Photovoltaic technologies. Energy Policy 2008;36:4390–6.
[6] Goldemberg J, Coelho ST, Lucon O. How adequate policies can push renewable. Energy Policy 2004;32:1141–6.
[7] Pop-Eleches G. From economic crisis to reform: IMF programs in Latin America and Eastern Europe. Princeton: Princeton University Press; 2009.
[8] Rocha L, Fidelis N, Pinguelli L. The paradigm of sustainability in the Brazilian energy sector. Renewable and Sustainable Energy Reviews 2007;11:1558–70.
[9] Arango S, Dyner I, Larsen ER. Lessons from deregulation: understanding electricity markets in South America. Utilities Policy 2006;14:196–207.
[10] Dyner I, Arango S, Larsen ER. Understanding the Argentinean and Colombian electricity markets. In: Sioshansi F, Pfaffenberger W, editors. Electricity market reform. Oxford: Elsevier; 2006. p. 595–616.
[11] IEA. Key world energy statistics. Paris, France: International Energy Agency OECD/IEA; 2008.
[12] Zuluaga M, Dyner I. Incentives for renewable energy in reformed Latin-American electricity markets: the Colombian case. Journal of Cleaner Production 2007;15:153–62.
[13] Armstrong M, Cowan S, Vickers J. Regulatory reform. Cambridge: MIT Press; 1994.
[14] Bacon RW, Besant-Jones J. Global electric power reform: privatization and liberalization of the electric power industry in developing countries. Annual Review of Energy and Environment 2001;26:331–59.
[15] Newbery DM. Privatization, restructuring and regulation of network utilities. Cambridge: MIT Press; 2001.
[16] Raineri R. Chile: where it all started. In: Sioshansi F, Pfaffenberger W, editors. Electricity market reform. Oxford: Elsevier; 2006. p. 77–108.
[17] Larsen ER, Dyner I, Bedoya L, Franco C. Lessons from deregulation in Colombia: successes, failures and the way ahead. Energy Policy 2004;32:1767–80.
[18] Hermes de Araujo JL. The case of Brazil: reform by trial and error? In: Sioshansi F, Pfaffenberger W, editors. Electricity market reform. Oxford: Elsevier; 2006. p. 565–94.
[19] IEA. Renewables for power generation status & prospects. Paris, France: International Energy Agency, OECD/IEA; 2003.
[20] Klimpt J-E, Rivero C, Puranen H, Koch F. Recommendations for sustainable hydroelectric development. Energy Policy 2002;30:1305–12.
[21] Caetano AC. Assessment and statistics of Brazilian hydroelectric power plants: dam areas versus installed and firm power. Renewable and Sustainable Energy Reviews 2008;12:1843–63.
[22] Sternberg R, Hydropower:. Dimensions of social and environmental coexistence. Renewable and Sustainable Energy Reviews 2008;12:1588–621.
[23] Coviello MF. Entorno Internacional y Oportunidades para el Desarrollo de las Fuentes Renovables de Energía en los Países de América Latina y el Caribe. Santiago de Chile: CEPAL; 2003, Serie CEPAL 63.
[24] Krauter DC, Kissel JM. RE in Latin America: actual state and potential of renewable energies in the region. Refocus 2005;6:20–6.

[25] Botero S, Isaza F, Valencia A. Evaluation of methodologies for remunerating wind power's reliability in Colombia. Renewable and Sustainable Energy Reviews 2010;14:2049–58.
[26] Belmonte S, Núñez V, Viramonte JG, Franco J. Potential renewable energy resources of the Lerma Valley, Salta, Argentina for its strategic territorial planning. Renewable and Sustainable Energy Reviews 2009;13:1475–84.
[27] OLADE. Energy statistics report 2006. Latin American Energy Organization OLADE, Quito; 2007.
[28] MINEM. Plan Referencial de Electricidad 2008–2017. Ministerio de Minas y Energía, Peru; 2009.
[29] CDEC-SIC. Operation statistics 1990/1999. Central interconnected electric system/load economic dispatch center: Santiago, Chile; 2000.
[30] CDEC-SIC. Operation statistics 1999/2008. Central interconnected electric system/load economic dispatch center: Santiago, Chile; 2009.
[31] Secretaría de Energía, Información del Mercado Eléctrico Argentino, Ministerio de Planificación Federal, Buenos Aires, Argentina. Available from: http://energia3.mecon.gov.ar, last visit October 2009.
[32] Brazilian Energy Balances. Brazilian Federal Government, Ministry of Mines and Energy – MME: Brasília, Brazil; 2009.
[33] UPME. Boletín Estadístico de Minas y Energía. Unidad de Planeamiento Minero Energético, Ministerio de Minas y Energía, Colombia (various years). Available from: http://www.upme.gov.co/; 2009.
[34] Newbery D. Electricity liberalization in Britain: the quest for a satisfactory wholesale market design. The Energy Journal 2005;26:43–73.
[35] DECC. Energy statistics: electricity. Department of Energy and Climate Change, UK. Available from: http://www.decc.gov.uk/, last visit September 2009.
[36] Cramton P, Stoft S. Forward reliability markets: less risk, less market power, more efficiency. Utilities Policy 2008;16:194–201.
[37] Diaz HF, Markgraf V. El Niño and the southern oscillation: multiscale variability and global and regional impacts. Cambridge University Press; 2000.
[38] Waylen PR, Poveda G. El Niño-Southern oscillation and aspects of western South America hydro-climatology. Hydrological Processes 2002;16:1247–60.
[39] Pereira AF, Salem A, Schaeffer R, Rodrigues R, Moreira BS, Leal IV, Pereira AO, Ferreira SH. The vulnerability of renewable energy to climate change in Brazil. Energy Policy 2009;37:879–89.
[40] The Economist, Argentina's chaotic energy policies; June 14th 2007.
[41] Victor DG. Gas and oil do not mix in the chaotic world of energy policy. Financial Times: London; May 9th 2006.
[42] Portafolio, Cortes de gas mostraron descoordinación entre actores del negocio y responsabilidad compartida. Available from: www.portafolio.com.co/economia/pais/ARTICULO-WEB-NOTA_INTERIOR_PORTA-6282768.html, last visit November, 2009.
[43] Dyner I, Larsen ER. From planning to strategy in the electricity industry. Energy Policy 2001;29:1145–54.
[44] Winskel M. When systems are overthrown: the 'dash for gas' in the British electricity supply industry. Social Studies of Science 2002;32:563–98.
[45] IEA. Statistics and balances. International Energy Agency, OECD/IEA. Available from: http://www.iea.org/Textbase/stats/index.asp, visited in October 2009.
[46] World Energy Council. Survey of energy resources, Interim Update 2009, London, United Kingdom; 2009.
[47] Nagayama H. Effects of regulatory reforms in the electricity supply industry on electricity prices in developing countries. Energy Policy 2007;35:3440–62.
[48] IEA. Global renewable energy: policies and measure. International Energy Agency OECD/IEA. Available from: http://www.iea.org/textbase/pm/grindex.aspx, visited in August 2009.
[49] Farinelli U. Energy as a tool for sustainable development for African, Caribbean and Pacific Countries, European Commission and the United Nations Development Programme, European Commission, Brussels, Belgium; and United Nations, New York, USA; 1999.
[50] Pereira MG, Vasconcelos M, da Silva NF. Rural electrification and energy poverty: empirical evidences from Brazil. Renewable and Sustainable Energy Reviews 2010;14:1229–40.
[51] Cherni J, Preston F. Rural electrification under liberal reforms: the case of Peru. Journal of Cleaner Production 2007;15:143–52.
[52] Huacuz JM. Overview of renewable energy sources in Latin America, International Electrical Research Exchange. Central American Forum: San José Costa Rica; November 2003.
[53] Guzowski C, Recalde M. Renewable energy in Argentina: energy policy analysis and perspectives. International Journal of Hydrogen Energy 2008;33:3592–5.
[54] Marques R, Salem A. Incentive policies for promoting wind power production in Brazil: Scenarios for the Alternative Energy Sources Incentive Program (PROINFA) under the New Brazilian electric power sector regulation. Renewable Energy 2008;33:65–76.
[55] Boyd E, Hultman N, Timmons Roberts J, Corbera E, Cole J, Bozmoski A, Ebeling J, Tippman R, Mann P, Brown K, Liverman D. Reforming the CDM for sustainable development: lessons learned and policy futures. Environmental Science & Policy 2009;12:820–31.
[56] UN, Kyoto Protocol. United Nations Framework Convention on Climate Change, United Nations; 1998. Available from: http://unfccc.int/resource/docs/convkp/kpeng.pdf#page=12).
[57] UNFCCC. About the clean development mechanisms, United Nations Framework Convention on Climate Change. Available from: http://cdm.unfccc.int/Statistics/Registration/RegisteredProjByRegionPieChart.html, last visit September 2009.
[58] Schneider M, Holzer A, Hoffmann VH. Understanding the CDM's contribution to technology transfer. Energy Policy 2008;36:2930–8.
[59] Lloyd B, Subbarao S. Development challenges under the Clean Development Mechanism (CDM) – Can renewable energy initiatives be put in place before peak oil? Energy Policy 2009;37:237–45.
[60] Kissel JM, Krauter SC. Adaptations of renewable energy policies to unstable macroeconomic situations – Case study: wind power in Brazil. Energy Policy 2006;34:3591–8.
[61] Komor P, Bazilian M. Renewable energy policy goals, programs, and technologies. Energy Policy 2005;33:1873–81.
[62] IEA. Tackling investment challenges in power generation in IEA Countries. International Energy Agency OECD/IEA, Paris, France; 2007
[63] Owen AD. Renewable energy: externality costs as market barriers. Energy Policy 2006;34:632–42.
[64] Cavalieri C, Larsen ER, Dyner I. The privatization of EEB: from cash drain to major contributor. Energy Policy 2007;35:1884–95.
[65] Caspary G. Gauging the future competitiveness of renewable energy in Colombia. Energy Economics 2009;31:443–9.
[66] Gavronskia JD, Sampaio CH. Thermal and renewable sources to sustain the growth of the Brazilian Electric System. Utilities Policy 2007;15:278–80.
[67] Peláez-Samaniego MR, Garcia-Perez M, Cortez LAB, Oscullo J, Olmedo G. Energy sector in Ecuador: current status. Energy Policy 2007;35:4177–89.
[68] Dyner I, Franco CJ, Arango S. El Mercado Mayorista de Electricidad Colombiano, Colección Facultad de Minas 120 años, Medellín, Colombia; 2008.